Do Bypass Systems Protect Juvenile Salmonids At Dams?

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Abstract–Bypass systems at dams on the Columbia and Snake Rivers divert large numbers of juvenile salmonids (*Oncorhynchus* spp.) away from turbine intakes and downstream into tailrace areas. However, few rigorous assessments of comparative survival have been made between bypassed fish and those passing through turbines. A study was initiated at Bonneville Dam in 1987 to provide definitive information regarding passage survival. Results to date show bypassed fish had lower survival than fish passing the dam through turbines or spillways. Fish exiting the bypass system had elevated plasma concentrations of cortisol (an index of stress), but physical injuries were not apparent. One likely cause for decreased survival of bypassed fish was predation by northern squawfish (*Ptychocheilus oregonensis*) on fish exiting the bypass outlet. Study results indicated that bypass operational procedures, as well as location and physical conditions at the bypass outlet, favor high predation. Factors contributing to high predation include: 1) river-water velocity of less than 1.2 m/s at the bypass exit; 2) proximity of the bypass exit to predator sanctuary areas; 3) location of the bypass exit at a curved reach of river where flow was directed toward shorelines; 4) poor dispersal of released fish, resulting in increased juvenile salmon density in the migration route; 5) disorientation of juvenile salmonids upon exiting the bypass outlet; and 6) continuous release at one site.

Introduction: Passage Survival of Juvenile Salmonids at Dams

Since dams were first constructed on the Columbia and Snake Rivers, concern for survival of juvenile salmonids (*Oncorhynchus* spp.) passing through turbines and over spillways has prompted research to identify the specific hazards of passage and to develop methods for safe passage. Holmes (1952) described research conducted from 1939 to 1945 at Bonneville Dam to evaluate differences in survival between the standard passage routes. Results of this study, based on adult recoveries, indicated an estimated average turbine passage mortality of about 12%. However, high variability in data among years and suspected high mortality during test-fish releases prompted continued research, focusing on survival of juveniles recovered immediately after passage.

Several net-recovery systems that attached to the downstream face of the powerhouse were developed (Webber 1954, Long and Marquette 1964), but these were unsuccessful due to low recovery percentages or substantial injury and mortality from the recovery process. In other studies, individual fish were placed in gossamer bags attached to balloons, which inflated after passage through the turbines and spillway, allowing recovery (U.S. Army Corps of Engineers 1957). However, data from this research were criticized because of the abnormal swimming behavior of these test fish and the protective effects of the bag.

Predation on juvenile salmonids after passage through dams has been identified as a serious problem. Long et al. (1968) found that northern squawfish (*Ptychocheilus oregonensis*) near Ice Harbor Dam on the Snake River were preying extensively on juvenile salmonids and that juvenile salmonids released into the backroll of the turbine discharge plume (currents moving upstream) at Ice Harbor Dam suffered 32% greater losses (presumed from predation) than cohorts exiting directly downstream in the frontroll of the turbine discharge plume (currents moving downstream). Assumed heavy predation in the tailrace area prompted the U.S. Army Corps of Engineers (1957) and Johnson (1970) to identify tailrace-release locations at Bonneville Dam that would direct juvenile salmonids quickly downstream, away from the zones of heavy predation.

Concurrent with passage-survival research, other programs have investigated intercepting juvenile salmonids at the upstream face of dams (overflow into ice and trash sluiceway) and in turbine intakes using guidance devices such as submersible traveling screens (Farr 1974). These devices guide fish into gatewells and shunt them into conduits that bypass turbines and discharge the fish downstream. Studies of the ice and trash sluiceways and submersible traveling screens to shunt juveniles past turbines began in the 1950s and the 1960s, respectively, and continue to date at most dams on the mainstem Columbia and Snake Rivers. The effectiveness of equipment and procedures at interception, and the condition of the fish following diversion, were constantly assessed during this period. However, survival of juvenile salmonids exiting those bypass systems was infrequently compared to that of others exiting alternate structures of the dam or to that of fish released at locations downstream from the dam. The complexity of conditions, the extensive effort required, and the large numbers of fish necessary for adequate statistical power have stifled efforts at identifying survival differences among passage routes (Sims and Johnsen 1977 and 1978, Mitchimoto and Junge 1980, McConnell and Muir 1982, Krcma et al. 1984, Park and Achord 1987).

Research to evaluate release methods for juvenile salmonids exiting bypass systems was conducted in the 1970s. Sims and Johnsen (1977 and 1978) provided evidence that release location and time of day were important to survival of juvenile salmonids exiting a bypass system at McNary Dam. Fish exiting at the standard location at night suffered greater mortality (presumably from predation) than fish released in daylight or at a nearshore, seldom-used outlet. Based on earlier observations of poor survival for fish released into the backroll, Long et al. (1976) evaluated a method of hydraulically jettisoning fish from the tailrace deck of a dam into the frontroll. Unfortunately, their only prototype failed to propel the fish and water stream the 22 m necessary to reach the frontroll, and research was discontinued.

Passage Route Survival Comparisons at Bonneville Dam

There were several compelling reasons for reexamining juvenile salmonid passage survival at Bonneville Dam. Information specific to all passage routes was needed for management of fish passage relative to power production at the two powerhouses. As the lowermost dam on the Columbia River, more juvenile salmon pass Bonneville Dam than any other dam in the system. Moreover, no comprehensive assessment of passage survival was conducted at the dam after construction of the spillway flow deflectors in 1975, the Second Powerhouse in 1983, and the downstream migrant bypass systems at the First and Second Powerhouses in 1981 and 1984, respectively. Those bypass systems at the First and Second Powerhouses were state of the art and were anticipated to provide the safest possible passage for juvenile salmonids. The bypass system outlets were positioned such that fish exited underwater, downstream from the turbine boil at the flow intersection between the two northernmost turbines. These sites were located away from the shoreline, the river-bottom, and any structure which could provide sanctuary for piscivores.

In 1987, the National Marine Fisheries Service (NMFS) began a multiyear study in cooperation with the U.S. Army Corps of Engineers (COE) to evaluate survival of subyearling fall chinook salmon (*O. tshawytscha*) passing Bonneville Dam. During June, July, and August 1987 through 1990, and in 1992, groups of differentially marked juvenile chinook salmon were simultaneously released to pass Bonneville Dam via various routes: the Second Powerhouse bypass and turbines, the First Powerhouse bypass and turbines, and the spillway (Fig. 1). Additional releases were made in the tailrace at the downstream edge of the turbine boil (frontroll) and about 2.5 km downstream from the dam. Not all passage routes were assessed each year. To date, about 9.5 million fish have been released. Estimates of short-term relative survival are based on recoveries of juveniles by beach and purse seines at Jones Beach, which is located at the head of the Columbia river estuary (River Kilometer 75) (Ledgerwood et al. 1992). Estimates of long-term relative survival will be based on recoveries of tagged adult fish from the fisheries and from hatchery escapement.

The most significant and unexpected finding of the passage-survival study at Bonneville Dam was that fish passing through the new bypass systems survived at a lower rate than fish passing through turbines. This suggested little survival advantage associated with the bypass systems. In the first two years (1987 and 1988), recoveries of bypass-released groups of fish were significantly less than recoveries of turbine-released groups: mean differences were 10.8 and 13.6%, respectively (Table 1). In 1989 and 1990, recoveries of bypass-released groups were also less (though not significantly) than recoveries of turbine-released groups (mean differences were 3.3 and 2.5%, respectively). The difference between the first two years and the second two years may be associated with greater river flow during tests conducted in the latter. Recoveries of bypass-released groups at the Second Powerhouse averaged 8.3% less than those of tailrace-released groups, 16.6%

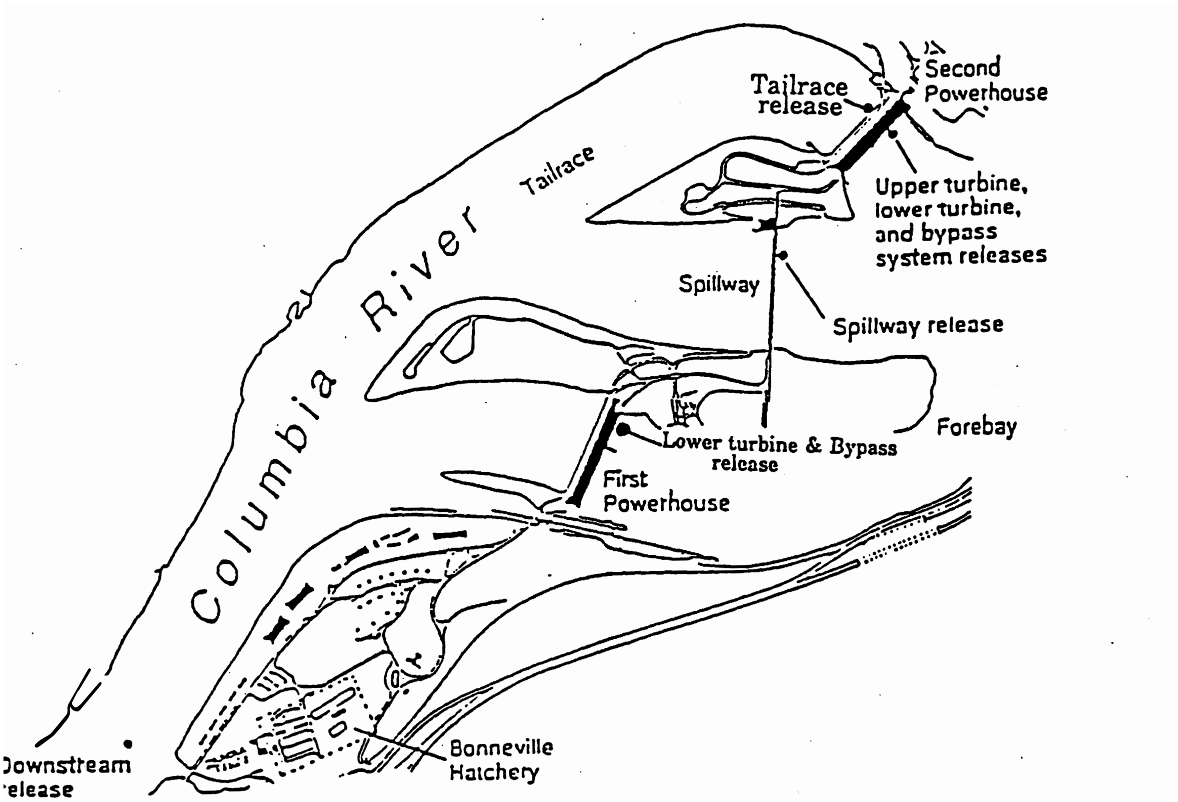

Figure 1.--Bonneville Dam and vicinity showing release locations for subyearling chinook salmon during 1987-1992 studies.

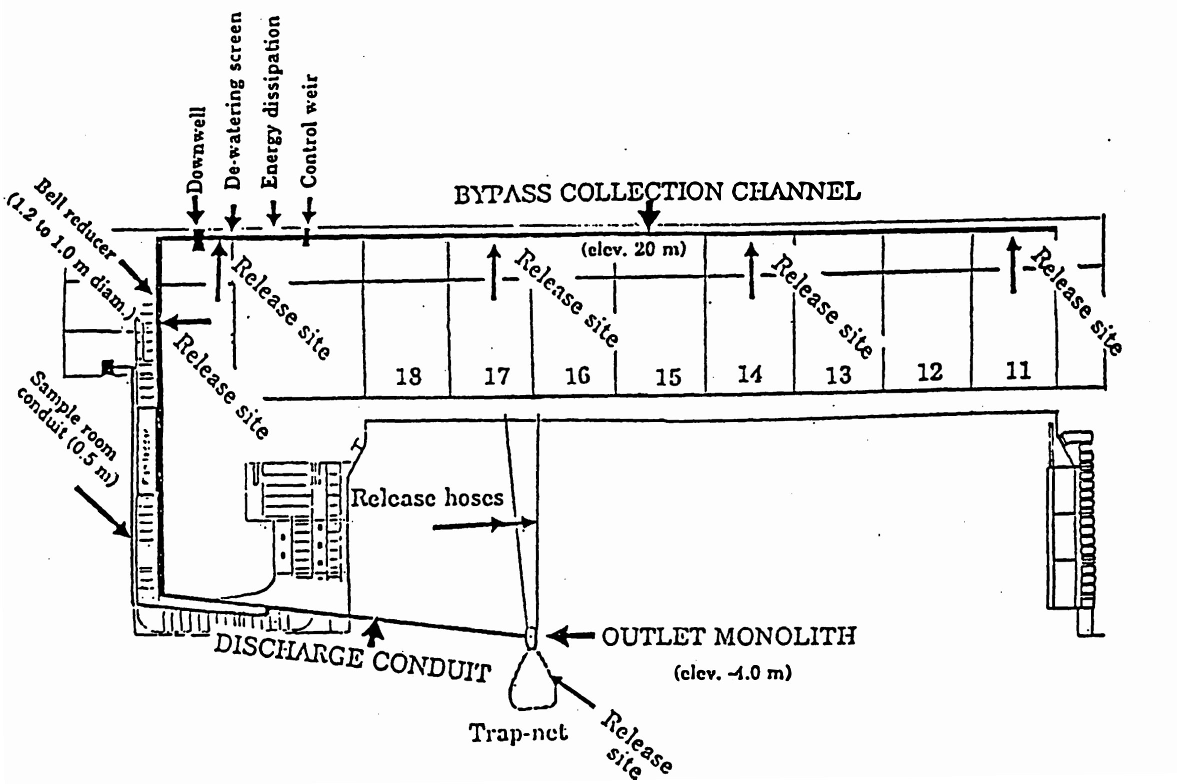

Figure 2.--The downstream migrant bypass system at Bonneville Dam Second Powerhouse showing fish release sites.

less than those of spillway-released groups, and 17.4% less than those of downstream-released groups. The spillway-released group comparison is noteworthy because, while spillway passage has long been believed to be the safest route of dam passage for outmigrating juvenile salmonids, bypass passage was expected to be at least similar.

In 1992, the fifth year of releases, recoveries of First Powerhouse bypass-released groups were significantly less than recoveries of turbine-released groups (11.8%) and downstream released groups (28.3%). Although several years remain before data on adult returns from the 1992 releases are complete, preliminary results from adult recoveries of releases in earlier years suggest that survival of bypass-released fish is not significantly different from that of turbine-released fish--again suggesting a lack of benefit from bypass passage (Gilbreath et al. 1993).

Evaluation of the Bypass System at Bonneville Dam

Early results of passage-survival tests conducted from 1987 to 1988 prompted a change in the research direction to focus on the detrimental impacts to outmigrating juvenile salmon from using the bypass system at the Second Powerhouse. Decreased survival may be a consequence of physical injury during passage through the system, and/or enhanced predation in the tailrace of the dam.

An examination of the physical features of the bypass system by NMFS and the COE to elucidate possible causes for the decreased survival did not reveal any obvious problems. A video inspection of the discharge conduit revealed no structural problems sufficient to cause injuries to fish. Water velocities adjacent to the bypass outlet varied from 1 to 1.6 m/s, similar to model predictions, and areas with velocities of that magnitude are poor habitat for northern squawfish (Faler et al. 1988). Purse seining at the bypass outlet produced little evidence of injury or mortality to salmonids, although insufficient fish were recovered to allow an accurate assessment.

In 1990, we began using a trap-net recovery system to assess the physical condition of outmigrants following passage through the bypass system (Fig. 2). The trap-net was attached directly to a steel carriage, which was permanently affixed to the bypass outlet. Marked, hatchery-reared yearling chinook, subyearling chinook, and coho (*O. kisutch*) salmon and steelhead (*O. mykiss*), and run-of-the-river yearling and subyearling chinook and coho salmon were released at various locations in the bypass system and trap-net. They were then recovered and examined for scale loss, injury, mortality, and 48-hr delayed mortality. Concentration of blood plasma cortisol was measured in run-of-the-river yearling and subyearling chinook salmon as an index of stress.

The trap-net recovered 80-100% of the live test fish and 93-100% of the fish killed just prior to release into the bypass channel. The high recovery rate of killed fish allowed us to assume that injured, moribund, and dead test fish exiting the bypass were represented proportionally in recovery data. Yearling hatchery fish showed no evidence of effects from passage through the bypass system. Hatchery subyearling and run-of-the-river subyearling and yearling salmonids showed higher descaling and mortality than their respective cohort controls. The detrimental impacts increased with increased distance of passage through the bypass system, which is about 420 m long. However, a substantial portion of the injuries and mortality were thought to be a consequence of recovery in the trap-net at water velocities ranging from 1 to 1.5 m/s rather than from passage through the bypass system. Differences between test groups were probably the result of varying duration of exposure to potential stressors and exhaustion, both related to the time necessary to traverse the bypass system. Concentrations of blood plasma cortisol were significantly greater for fish passing through the bypass system than for controls released directly into the trap net.

Aspects of the Bypass Systems Which May Cause Decreased Survival

Studies of northern squawfish in the tailrace of Bonneville Dam indicated greater predation on juvenile salmonids exiting the bypass system than from other locations at the dam. Ward et al. (1992) stated that trolling with lures at the bypass outlet produced the highest catches of northern squawfish--substantially higher than at any other location in the forebay or tailrace of the dam. In 1990 and 1992, greater percentages of bypass-released fish than tailrace- or turbine-released fish were consumed by northern squawfish (Thomas Poe, U.S. Fish and Wildlife Service, Cook, WA. personal communication).

It is probable that reduced survival of test fish bypassed through the Bonneville Dam Second Powerhouse in the summers of 1987-1992 resulted from predation by northern squawfish, which congregated at the release

Table 1.--Differences in relative survival between fish passing through the bypass systems and other passage routes at Bonneville Dam based upon juvenile recovery data from estuarine sampling.

Release site/ passage route	Percent difference of bypass recoveries from indicated treatment[a] 1987	1988	1989	1990	1992	Average
			Second Powerhouse Bypass			
Turbine:	Released at the ceiling and mid-depth of the turbine intake. Passage through the turbine and through the Second Powerhouse tailrace.					
	-10.8*	-13.6*	-3.3	-2.5[b]	---	-7.6*
Tailrace:	Released at the downstream side of turbine discharge boil. Passage through the Second Powerhouse tailrace.					
	----	-14.1*	-7.3	-3.6	---	-8.3*
Spillway:	Released 0.5 m above spillway crest. Passage over the spillway, through stilling basin and spillway tailrace.					
	----	----	-16.6*	----	---	-16.6*
Downstream:	Released downstream of dam and tailraces at a swift water site.					
	----	-23.1*	-11.6*	----	---	-17.4*
			First Powerhouse Bypass			
Turbine:	Released at mid-depth of the turbine intake. Passage through the turbine and through the First Powerhouse tailrace.					
	---	---	---	---	-11.8*	-11.8*
Downstream:	Released downstream of dam and tailraces at a swift water site.					
	---	---	---	---	-28.3*	-28.3*

[a] Calculated using annual means for recovery percent of treatment groups,
where: BY = bypass, and TR = other treatment groups/passage routes.
$[(BY\% - TR\%) \div TR\%] \times 100$.

[b] Only the mid-depth release site was used to provide increased numbers of replicates.

* Statistically significant at P = 0.95.

site due to the continuous emergence of juvenile salmonids at a single location. Moreover, exhaustion associated with bypass passage and elevated plasma cortisol likely diminished the predator-avoidance capabilities of juvenile salmonids. Laboratory studies have shown that elevated plasma cortisol and/or severe turbulence is associated with loss of equilibrium and abnormal avoidance behavior (Groves 1972, Sigismondi and Weber 1988, Olla and Davis 1992).

Conclusions

At Bonneville Dam in the summers of 1987-1992, estimated passage survival for juvenile fall chinook salmon released into the bypass systems was lower than for other dam passage routes, and substantially lower than for fish released 2.5 km downstream from the dam. Other research suggested greater predation by northern squawfish on test fish leaving the bypass system than on test fish discharged at other locations. Conditions within the bypass conduit appeared to cause few injuries, but elevated plasma cortisol and exhaustion associated with passage may have compromised the ability of the juvenile salmon to avoid predators. Other factors contributing to increased predation include: 1) low water velocity (less than 1.2 m/s) immediately downstream from the bypass exit; 2) proximity of the bypass exit to the shoreline or river bottom, which provided predator sanctuary; 3) release of fish into a curved reach of river where current was directed toward the shoreline rather than parallel to it; 4) poor downstream dispersal of released fish, resulting in increased juvenile salmon density in the migration route; 5) disorientation of juvenile salmonids upon exiting the bypass outlet; and 6) increased predator attraction by the continuous release of juvenile salmon at a single location.

Rigorous evaluations of bypass survival at other dams on the mainstem Columbia and Snake Rivers have not been conducted. In light of the poor survival of outmigrating subyearling salmonids passing Bonneville Dam via the bypass systems, such evaluations of bypass systems at other dams should be pursued.

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